AD-A013 691

PROTON PRECIPITATION BY A WHISTLER-MODE WAVE FROM A VLF TRANSMITTER

Harry C. Koons

Aerospace Corporation

Prepared for:

Space and Missile Systems Organization

14 July 1975

Proton Precipitation by a Whistler-Mode Wave from a VLF Transmitter

H. C. KOONS
Space Physics Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, Calif. 90245

14 July 1975

Interim Report

Prepared for

SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
Los Angeles, Calif. 90045

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SAMSO-TR-75-187	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROTON PRECIPITATION BY A WHISTLER-MODE WAVE FROM A VLF TRANSMITTER		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER TR-0076(6960-02)-1
7. AUTHOR(s) Harry C. Koons		8. CONTRACT OR GRANT NUMBER(s) F04701-75-C-0076
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Aerospace Corporation El Segundo, Calif. 90245		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Space and Missile Systems Organization Air Force Systems Command Los Angeles, Calif. 90045		12. REPORT DATE 14 July 1975
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Proton Precipitation
Whistler Mode
VLF

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Protons with 50 keV < E < 530 keV were detected by sensors aboard satellite 1972-76B at an altitude of 700 km in the region conjugate to the transportable very-low-frequency (TVLF) transmitter which was being operated near Anchorage, Alaska ($L \sim 4$). Temporal maxima in the proton count rates can be identified on a one-to-one basis with short pulsed transmissions by the VLF transmitter. The observed time delay between the center of a transmitted pulse and the detection of the next maximum in

19 KEY WORDS (Continued)

20 ABSTRACT (Continued)

the proton count rate at the sensor agrees well with the delayed predicted from a simple plasmaspheric model.

ACCESSION for		
NTIS	White Section	☐
DDC	Buff Section	☑
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CODES		
Dist.	AVAIL. and/or SPECIAL	
A		

Approved

G. A. Paulikas, Director
Space Physics Laboratory

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Ronald C. Lawson, 2nd Lt.
United States Air Force
Technology Development Division
Deputy for Technology

PREFACE

The author is indebted to D. R. Croley for data from the P72-1 proton detector, to B. C. Edgar for computing the ray trajectories, to W. C. Campbell for the micropulsation data from College, Alaska, to R. L. Dowden for the VLF and micropulsation data from Dunedin, and to R. E. Barrington for the VLF data from ISIS 2. It is a pleasure to acknowledge productive discussions with J. B. Blake and M. Schulz. This work was supported in part by the National Science Foundation under Grant GA-37730 and in part by the U.S. Air Force Space and Missile Systems Organization (SAMSO) under contract F04701-74-C-0075.

CONTENTS

Preceding page blank

FIGURES

ABSTRACT

Protons with 50 keV < E < 530 keV were detected by sensors aboard satellite 1972-76B at an altitude of 700 km in the region conjugate to the transportable very-low-frequency (TVLF) transmitter which was being operated near Anchorage, Alaska (L ~ 4). Temporal maxima in the proton count rates can be identified on a one-to-one basis with short pulsed transmissions by the VLF transmitter. The observed time delay between the center of a transmitted pulse and the detection of the next maximum in the proton count rate at the sensor agrees well with the delay predicted from a simple plasmaspheric model.

PROTON PRECIPITATION BY A WHISTLER-MODE WAVE FROM A VLF TRANSMITTER

During the summer of 1973 a series of wave-particle interaction experiments was conducted by transmitting very-low-frequency (VLF) waves into the magnetosphere from a site near Anchorage, Alaska (L ~ 4) [Koons and Dazey, 1974]. During the overall period of operations from August 1 through September 14, electron and proton fluxes were routinely measured by instruments aboard satellite P72-1 (1972-76B) whenever the satellite was within ±30° longitude of the transmitter or its magnetically conjugate point. This satellite is in an approximately circular orbit at an altitude of 700 km. The orbit is sun-synchronous and lies approximately in the noon-midnight geographic meridional plane.

While the transmitter was in operation, twenty-four data acquisitions occurred either over the transmitter or over the conjugate region. The data from these twenty-four passes have been searched for evidence of

particles which precipitated to the satellite altitude because of wave-particle interactions involving the signals from the VLF transmitter. In this longitude range about the transmitter, all particles mirroring at or below the satellite are in the drift loss cone.

The Aerospace Corporation payload aboard P72-1 contained four proton detectors: a nickel foil covered channeltron, two proton telescopes with solid state detectors, and a scintillation spectrometer. The nickel foil detector was nominally sensitive to protons above 70 keV. However it had an efficiency of 18% at 50 keV relative to its efficiency at energies much greater than threshold. The geometric factor was 3.88×10^{-3} cm^2 sr. One proton telescope had a sharp threshold at 196 keV. The other detected protons between 314 keV and 527 keV. Each had a geometric factor of 4×10^{-3} cm^2 sr. The scintillation spectrometer used a pulse-shape discriminator scheme which enabled the instrument to differentiate between protons and electrons. A thin sheet of aluminized mylar covering the aperture allowed protons with energies >0.5 MeV to pass through. The pulse height thresholds of five channels were set to correspond to proton energies of 0.5, 1.5, 2.5, 4.0, and 6.0 MeV. The instrument had a very large geometric factor of 60 cm^2 sr.

During a data acquisition in the conjugate region at approximately 55° S, 161° W (geographic coordinates) at 11:35 UT, on September 11, 1973, temporal maxima in the proton fluxes measured by the nickel foil detector and both proton telescopes can be identified one-to-one with pulses from the VLF transmitter. The satellite, traveling northward, traversed L shells between L = 3.9 and L = 3.1. During this event no protons were detected by the scintillation spectrometer.

The P72-1 satellite is spin-stabilized with a spin period of 5 sec. The spin vector is normal to the orbital plane. During the proton precipitation event, the count rate (which is accumulated for 0.24 sec) maximized twice per spin period each time the detectors looked normal to the geomagnetic field. In Figure 1 these maximum count rates (which correspond to protons mirroring near the satellite altitude) from the nickel foil detector are plotted as a function of time. The largest proton fluxes measured by the three detectors occurred simultaneously at 11:35:31 UT. The measured values were 1.7×10^5 cm^{-2} sec^{-1} sr^{-1} for $E > 70$ keV, 2.4×10^4 cm^{-2} sec^{-1} sr^{-1} for $E > 196$ keV, and 4.2×10^3 cm^{-2} sec^{-1} sr^{-1} for $314 < E < 527$ keV. In general the data are not sufficient to determine if the spectrum has a local maximum in this energy range.

The pulse program transmitted by the VLF transmitter is shown above the detector count rates in Figure 1. It consisted of a series of double pulses. The first pulse in each pair was a long pulse which increased in length from 0.5 sec to 5 sec within the sequence. The long pulse was followed by a 0.25 sec gap and then a 0.25 sec pulse. In Figure 1 it is apparent that each pulse pair is followed several seconds later by a maximum in the flux of protons mirroring at the satellite. For the purposes of quantifying this delay, the time period between the center of the long pulse and the next local maximum in the proton flux is measured. This delay time is spanned by the arrows in Figure 1. The transmitter programmer is synchronized to WWV. The timing accuracy is ±2 msec. The tape-recorded data from the satellite are synchronized with the satellite clock, which is compared with universal time (UT) once per day. The time is routinely corrected for the drift of the satellite clock and for the propagation time from the satellite to the range tracking station. The

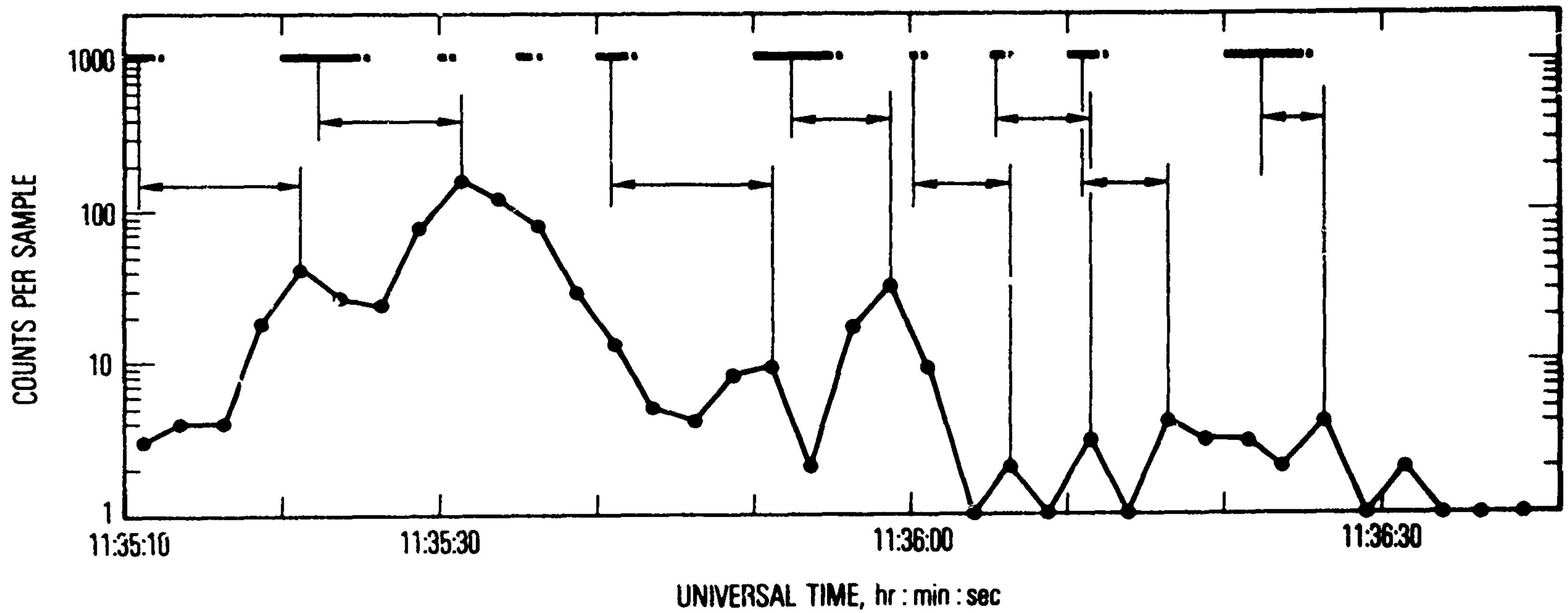

Fig. 1. Proton detector count rate as a function of time. The maximum count rate each half spin period (corresponding to locally mirroring protons) is plotted. The pulse program being transmitted by the VLF transmitter is shown at the top. The time delay between the pulse and the next maximum in the proton intensity is spanned by the arrows.

timing accuracy of the satellite data is estimated to be ±5 msec. The overall timing accuracy compared with the observed delays is better than one part in 10^3.

The signal from the VLF transmitter propagates through the magnetosphere in both ducted and non-ducted modes. Since the protons are observed over a range $\Delta L \sim 0.5$, it was probably the non-ducted mode that was responsible for the interaction. The velocity of the resonant protons and the expected delay between the time of transmission (taken at the center of the long pulse) and the time of proton detection has been calculated for a simple model magnetosphere. For this purpose the waves were taken to be unducted whistler-mode waves which interact at the equator with the protons through either a Doppler-shifted cyclotron resonance or a traveling-wave-tube (Landau) resonance. Since the proton gyrofrequency is much less than the wave frequency, proton velocities must satisfy the condition $\omega \approx \vec{k} \cdot \vec{v}$ for either resonance. It is important to note that this resonance condition requires that the waves and particles be traveling through the magnetosphere in the same direction. Since the waves are transmitted into the magnetosphere from the northern hemisphere, the protons which interact appropriately with the waves on their first pass through the equator are expected to precipitate in the southern hemisphere.

A diffusive-equilibrium model was chosen for the thermal plasma. The electron density at an altitude of 1000 km was taken to be 10^4 cm^{-3}. A whistler-mode ray-tracing program was used to compute the wave propagation time to the geomagnetic equator and the wave-normal angle at the equator. A typical ray path is shown in Figure 2. The time, τ_ω, required for the wave to reach the magnetic equator (where the interaction is assumed to have occurred) is a function of the value of L at the point where

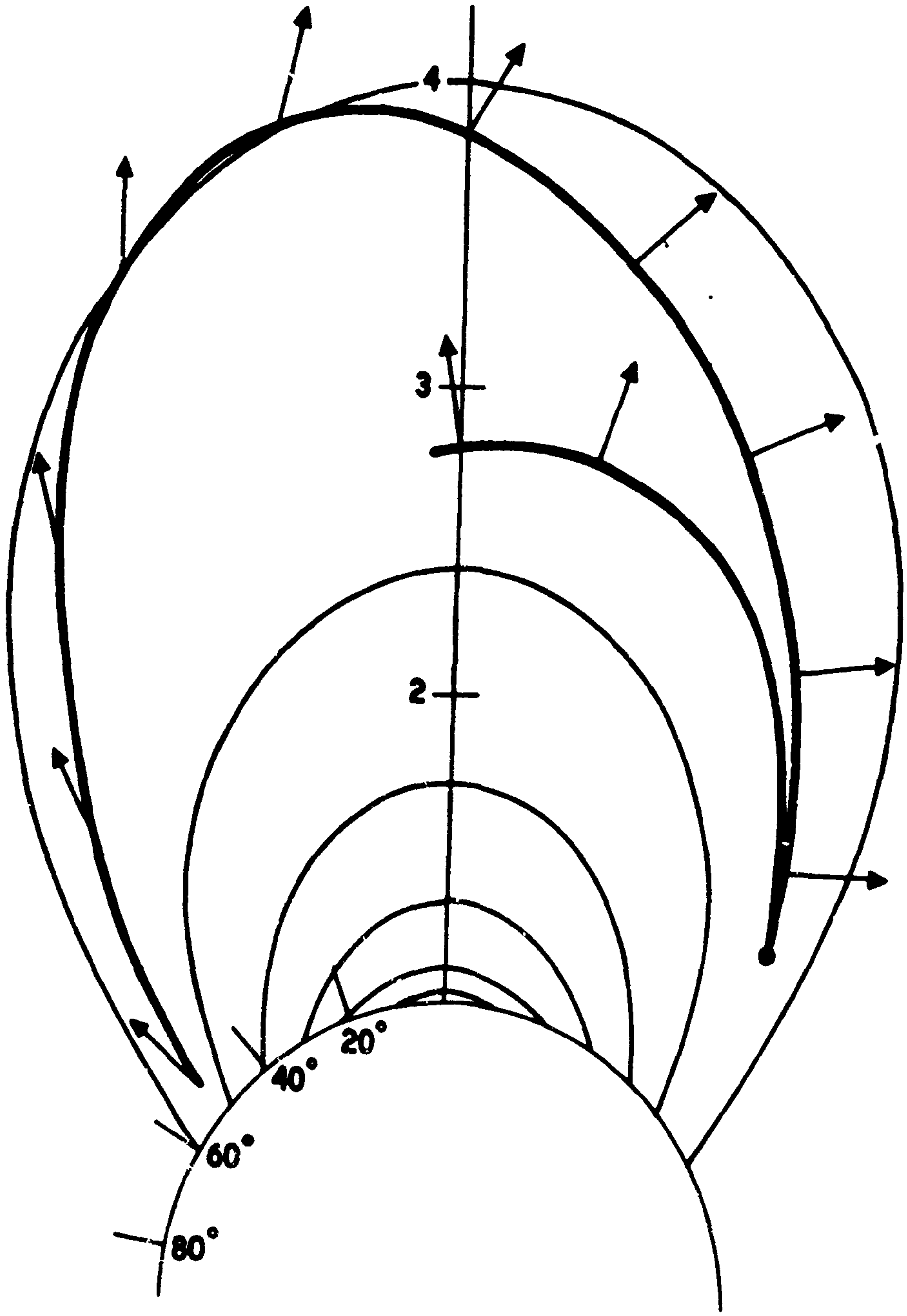

Fig. 2. Typical ray path for a non-ducted whistler-mode wave with a frequency of 6.6 kHz. The input latitude is 50.1° at an altitude of 1000 km where the electron density is taken to be 10^4 cm^{-3}.

the wave crosses the equator. This time varies from 1.2 sec at L = 3.3 to 2.8 sec at L = 3.9. The wave-normal angle at the equator was always found to be quite close to 60°.

The velocity of the resonant protons was then determined for the model magnetosphere. The proton resonant energy (derived from the parallel velocity of the resonant particles which is essentially equal to their total velocity at the equator) varies from 338 keV at L = 3.3 to 54 keV at L = 3.9. The time of flight of the protons from the interaction region at the equator to the satellite in the southern hemisphere was taken to be the quarter bounce period ($\tau_b/4$) of the resonant protons. The total delay time between the center of the pulse and the particle detection at the satellite was thus the sum of the time required for the wave to reach the equator and the quarter bounce time for the resonant protons. The observed and predicted delays for the event on September 11 are shown in Figure 3. For seven of eight consecutive maxima in the proton intensity, the standard deviation of the observed delay time from the predicted delay time is 0.45 sec.

The calculated travel times for both the waves and the protons are nearly proportional to the square root of the electron density. This is the only significant scale factor in the calculated delay time.

During the time period of this event, micropulsation data were available from College, Alaska and Dunedin, New Zealand. Both detectors were very quiet. VLF data were recorded on the ground in the conjugate hemisphere at Dunedin, New Zealand. No magnetospherically propagated signals, including whistlers generated by lightning strokes, were detected on the ground within 30 minutes of the P72-1 observations. VLF data were recorded by the ISIS 2 satellite over the conjugate region on a southbound

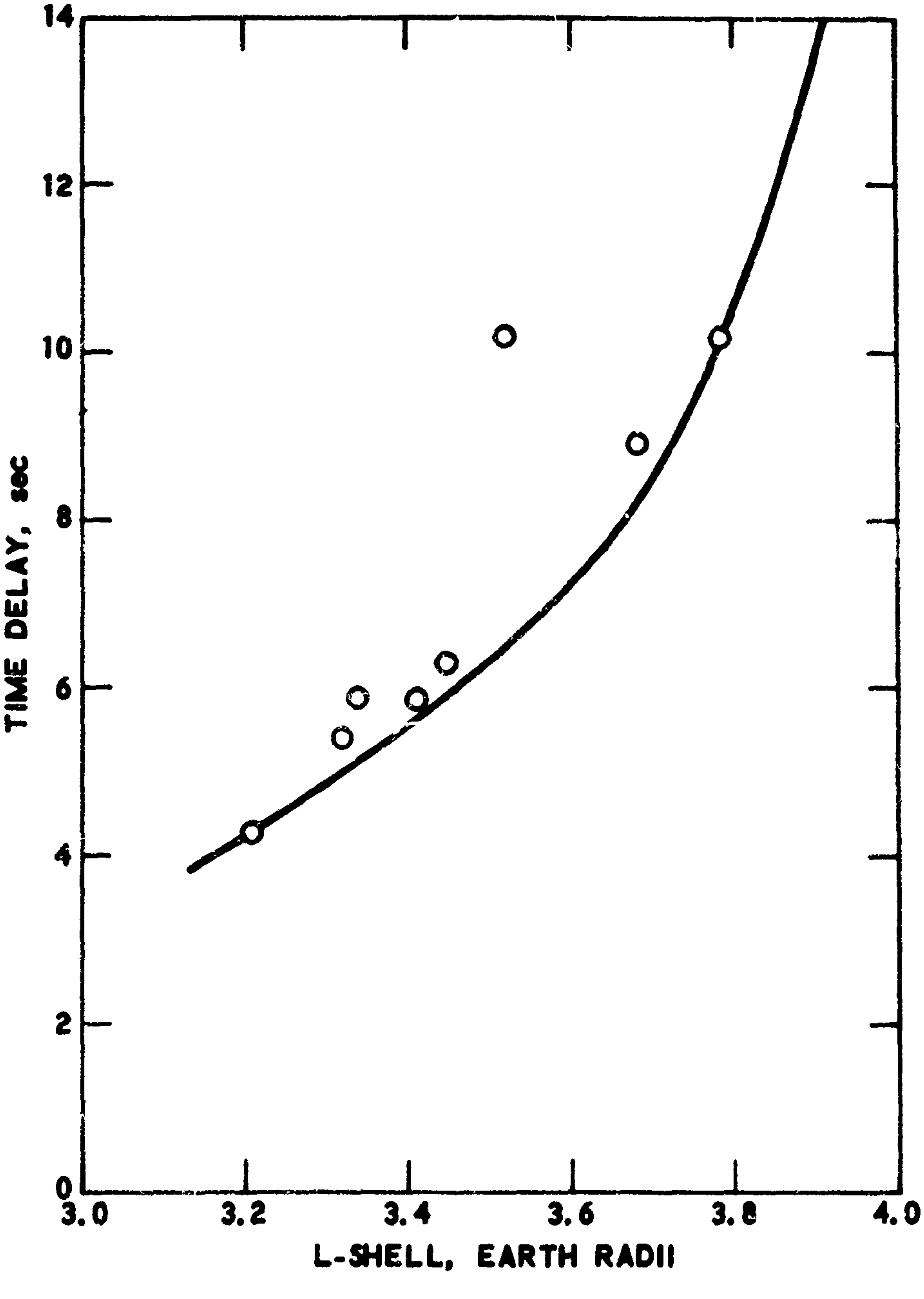

Fig. 3. Observed time delay (circles) between the center of the VLF pulse and the next maximum in the proton intensity. The calculated time delay (solid line) for a plasmapheric model assuming the plasmasphere is in diffusive equilibrium and that the electron density is 10^4 cm^{-3} at an altitude of 1000 km.

pass at 180° E longitude between 10:43 UT and 10:57 UT. During that time period the TVLF transmitter was alternately keyed on and off for one second intervals at 6.6 kHz. Although the TVLF signal is frequently detected by ISIS 2 throughout the region from 47° to 57° Invariant Magnetic Latitude in the conjugate region [Koons et al., 1974], the signal was not detected during the acquisition at 10:43 UT on September 11, 1973. During this pass a strong hiss band between the lower band limit and 2.5 kHz and a strong LHR noise band which decreased in frequency from 12 kHz at L = 2.3 to 4 kHz at L = 3.4 were observed. It is likely that the gain of the receiver was set at a low level by the large amplitudes of these signals. It is also possible that the signals from the TVLF transmitter were magnetospherically reflected above the satellite since the LHR frequency coincided with the transmitter frequency in the center of the latitude range of interest.

Two additional events were detected by the proton sensors on satellite P72-1. They confirm in detail the observations reported above. However, they also significantly complicate the picture. In addition to the maxima which occur at $\tau_{\omega} + (\tau_b/4)$, a second family of maxima occur with an observed delay equal to $\tau_{\omega} + (3\tau_b/4)$. This suggests that protons traveling both parallel and antiparallel to the direction of wave propagation interact with waves, and that the resonance condition is independent of the direction the proton is traveling. This picture is not consistent with present quasi-linear theories of wave-particle interaction.

REFERENCES

Koons, H.C. and M.H. Dazey: Transportable VLF Transmitter. ELF-VLF Radio Wave Propagation, edited by J. Holtet, p. 413, D. Reidel Publishing Company, Dordrecht, 1974.

Koons, H.C., B.C. Edgar, R.L. Dowden, C.G. Carrington, and L.E.S. Amon: Multipath Doppler Shifts in Man-Made VLF Signals. ELF-VLF Radio Wave Propagation, edited by J. Holtet, p. 311, D. Reidel Publishing Company, Dordrecht, 1974.

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space and missile systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch and reentry aerodynamics, heat transfer, reentry physics, chemical kinetics, structural mechanics, flight dynamics, atmospheric pollution, and high-power gas lasers.

Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Physics Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

THE AEROSPACE CORPORATION
El Segundo, California